BEFORE THE
PUBLIC SERVICE COMMISSION OF WISCONSIN

Application of Highland Wind Farm, LLC, for a Certificate of Public Convenience and Necessity To Construct a 102.5 Megawatt Wind Electric Generation Facility and Associated Electric Facilities, to be Located In the Towns of Forest and Cylon, St. Croix County, Wisconsin	Docket No. 2535-CE-100

Ex.-CW-Cook-2

Please enter the attached exhibit, Ex.-CW-Cook-2, *Wind Turbines and idiopathic symptoms: The confounding effect of concurrent environmental exposures*, by V. Blanes-Vidal and J. Schwartz, Neurotoxicology and Teratology, 2016.

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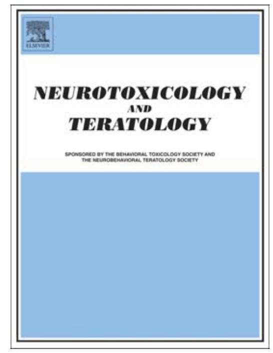

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Wind turbines and idiopathic symptoms: The confounding effect of concurrent environmental exposures

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Running title: Wind turbines, co-exposures and symptoms

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Abstract

Whether or not wind turbines pose a risk to human health is a matter of heated debate. Personal reactions to other environmental exposures occurring in the same settings as wind turbines may be responsible of the reported symptoms. However, these have not been accounted for in previous studies. We investigated whether there is an association between residential proximity to wind turbines and idiopathic symptoms, after controlling for personal reactions to other environmental co-exposures. We assessed wind turbine exposures in 454 residences as the distance to the closest wind turbine (D_w) and number of wind turbines <1000m (N_{w1000}). Information on symptoms, demographics and personal reactions to exposures was obtained by a blind questionnaire. We identified confounders using confounders' selection criteria and used adjusted logistic regression models to estimate associations. When controlling only for socio-demographic characteristics, $\log_{10}D_w$ was associated with "unnatural fatigue" (OR_{adj}=0.38, 95%CI=0.15-1.00) and "difficulty concentrating" (OR_{adj}=0.26, 95%CI=0.08-0.83) and N_{w1000} was associated with "unnatural fatigue" (OR_{adj}=1.35, 95%CI=1.07-1.70) and "headache" (OR_{adj}=1.26, 95%CI=1.00-1.58). After controlling for personal reactions to noise from sources different from wind turbines and agricultural odor exposure, we did not observe a significant relationship between residential proximity to wind turbines and symptoms and the parameter estimates were attenuated toward zero. Wind turbines-health associations can be confounded by personal reactions to other environmental co-exposures. Isolated associations reported in the literature may be due to confounding bias.

1. Introduction

Wind energy is the fastest-growing source of electricity in the world. It is considered a good alternative to fossil fuel-generated electricity and for that reason it has become a preferred option of renewable energy for many planners and governments. In Denmark, the world leader in total wind capacity per capita, wind power provided a record of 39.1% of Denmark's electricity consumption in 2014. The global benefits of wind energy in terms of reduced emissions of air pollutants are often emphasized, while local considerations receive relatively less attention. However, in recent decades, there has been a growing public interest on how features of modern life may pose threats to personal health, and wind energy is not an exception[1]. Concerns have been raised about the potential health effects of living close to wind turbines and as a result, epidemiological studies have been carried out to elucidate the health implications of wind industry.

However, whether or not there is a relationship between residential proximity to wind turbines and health is still a matter of debate. Population studies have not found consistent evidence indicating that exposure to wind turbines audible and inaudible noise has a direct effect on human physiological health (Pedersen et al., 2009; Van den Berg et al., 2008; Knopper et al., 2014). However, literature has also developed to suggest that there is a connection between wind turbines and health (Havas and Colling, 2011; Salt and Kaltenbach, 2011; Hanning and Evans, 2012; Bakker et al., 2012; Kuwano et al., 2013), Symptoms reported by people who live in close proximity to wind turbines have been idiopathic symptoms, such as sleep disturbance, fatigue, nausea, dizziness, headache, and lack of concentration, as well as annoyance (Chapman et al., 2013; Shepherd et al., 2011; McCallum et al., 2014; Kuwano et al., 2014; Pawlaczyk-Łuszczyńska et al., 2014). Pedersen (2011) reviewed the results of three cross-sectional studies (Pedersen and Persson-Waye, 2004; 2007; Pedersen et al., 2009), and found that annoyance was consistently directly associated with A-weighted sound pressure levels, but no other variable measuring health or well-being (e.g. headache, tiredness, sleep disturbance) was consistently related to sound pressure levels throughout the three studies.

One of the main methodological limitations of current studies on wind turbines and health associations is the poor control for potential confounders. Adjustment for confounding variables is a key step to obtain an unbiased estimate of the relationship between exposure and outcome in observational studies. Basic demographical features (such as age and gender) have been adjusted for in the analyses (Pedersen, 2011), but other possibly confounding factors have not been consistently controlled. Exposure to other environmental stressors occurring in the same settings as wind turbines may act as confounders and play an important role in physical symptom reporting. On-shore wind turbines are mainly placed in rural settings, and typical land use of rural areas are farming activities, which can be a source of offensive odors (Blanes-Vidal et al., 2009). Previous studies have demonstrated the relationship between agricultural odor annoyance and symptoms (Blanes-Vidal et al., 2014; Blanes-Vidal 2015). In addition, due to the rural context with low background noise and the specific type of transport (e.g. heavy truck loads, agricultural tractors), people in rural areas can experience significant exposure to road noise. Road noise annoyance has also been related with non-specific symptoms (Héritier et al., 2014). Despite these indications that negative reactions to odor and non-wind turbine noise may be important confounders, to date no study on the association between wind turbines and health has controlled for these other environmental factors.

In this study, we explored the associations between residential proximity to wind turbines and idiopathic symptoms, and investigated whether these relationships can be confounded by personal reactions to other environmental exposures occurring in the same settings as wind turbines.

2. Materials and methods

2.1. Data collection on demographics, potential confounders and symptoms

A cross-sectional, population-based study was conducted in six 12 kmx12 km non-urban regions distributed throughout Denmark (Blanes-Vidal et al., 2014). A total of 1120 households within the six study areas were randomly selected and a structured questionnaire was mailed from October 2011 to February 2012. The sample selection bias was minimized by approaching the residents randomly, irrespective of whether they lived in close proximity to wind turbines or not. The questionnaire was based on a standard questionnaire on indoor climate (Brauer et al., 2000), which includes items concerning symptoms, perceived environment and personal characteristics. Some supplementary questions were included, and the final questionnaire was the same as the one used in previous studies (Blanes-Vidal et al., 2012; 2014). Adults (>18 years old) living at the household (1 adult/household) were requested to fill and return the anonymous questionnaire. Research was conducted in accordance with principles of the Declaration of Helsinki and approved by the Danish Data Protection Agency (Datatilsynet).

To minimize self-selection bias, the intent of the study was fully masked by: (1) introducing the study as a study on living conditions in rural areas, (2) including questions about different environmental factors (i.e. odor, noise, dust and smoke) and symptoms that are in principle not related with wind turbines exposures (e.g. running nose), (3) mentioning multiple potential sources of annoyance different from wind turbines (i.e. traffic, factories, farms, fertilizer spreading) and (4) not mentioning the word “wind” and any of its forms (e.g. “wind turbine”, “wind power”, “wind energy”, “wind tower”) at any time in the survey.

The first part of the structured questionnaire included general socio-demographic and lifestyle data and an open-ended question whereby participants listed, according to their own experience, the main advantages and disadvantages of living in the countryside. The second part referred to environmental stressors, i.e. annoyance, health risk perception and behavioral interference experienced during the years 2010 and 2011 due to environmental odor, noise, dust and smoke. Questions regarding annoyance included: degree of perceived annoyance (estimated using the 5-point verbal annoyance scale, i.e. “0 = not annoyed”, “1 = slightly annoyed", "2 = moderately annoyed", "3 = very annoyed" and "4 = extremely annoyed") and origin (i.e., traffic, factory, farm, fertilizer spreading, unknown, or others). The specific questions (translated from Danish) were: "Have you, within the past two years, been annoyed by noise, odor, particulates or smoke in your home (inside or near)?" and "What was their origin?". Concerns about the adverse health impacts of these four environmental stressors at their residences were evaluated using a verbal scale (0 = not concerned; 1 = slightly concerned; 2 = very concerned). The specific question (translated from Danish) was: "Are you worried that some of the following conditions in your home can damage your health?". Finally, residents were asked whether the existence of each of these environmental stressors at their properties prevented them from properly ventilating their homes or from performing outdoor activities that they wished to (0 = no behavioral interference; 1 = behavioral interference). The specific question was "Are there circumstances that prevent you from airing enough out in the home or performing outdoor activities (e.e. BBQ) which you would like to?". The responses were: "Yes, outdoor noise", "Yes, outdoor odor", "Yes, outdoor dust", "Yes, outdoor smoke", "Yes, other factors (open response)" and "No".

The third part of the questionnaire referred to physical symptoms and health. Eleven symptoms were included: Five idiopathic symptoms that have been reported by residents who live in close proximity to wind turbines (i.e. dizziness, difficulty concentrating, headache, unnatural fatigue and nausea) and six irritation/respiratory symptoms that have been related to exposure to air pollutants (i.e. ''itching, dryness or irritation of eyes'', ''itching, dryness or irritation of the nose'', ''runny nose'', ''cough'', ''chest wheezing or whistling'' and ''difficulty breathing''). Unnatural fatigue ("unaturlig træthed" in Danish) is the fatigue that has no apparent cause, which could also be translated into English as "abnormal fatigue" or "unexplained fatigue". The six irritation/respiratory symptoms were "dummy symptoms", since association between proximity to wind turbines and these symptoms is unlikely. Residents were asked to estimate the frequency of symptoms within the last two years on a 0-4 scale: 0 = Never/Very rarely; 1 = Several times per year; 2 = Several times per month; 3 = Several times per week; 4 = Daily. Self-reported information on physician-diagnosed medical conditions was categorized into: 1) acute respiratory conditions, 2) chronic respiratory conditions, and 3) other chronic diseases.

2.2. Wind turbine exposures

Information on the wind turbines was obtained from the Danish register of wind turbines, a national database that contains information on location, size and output for each Danish power producing wind turbine (Danish Energy Authority, 2010). In this study we considered wind turbines that were operative 12 months or more, during 2 years before the population survey was mailed. Overall there were 5122 active on- and offshore wind turbines in Denmark. Of these, about 4717 were onshore and about 405 were offshore. A total of 219 on-shore wind turbines were sited in the studied rural regions. In these regions farm-related activities are the predominant land use. Other typical uses include residential land use (i.e. scattered residential dwellings and clustered non-farm settlements) and industrial land use (mainly agricultural-related local industries); intermixed with major and local roads.

In our study we used residential proximity to the source as a surrogate of exposure to wind turbines. Residential proximity has also been used is previous studies investigating potential wind turbines-health associations (Nissenbaum et al., 2012). Each home address and each wind turbine was geo-coded, and separate exposure estimates were developed on the basis of the distance from each house to the closest wind turbine (D_w), the number of wind turbines within 1000 m around participants' home (N_{w1000}), and the number of wind turbines within 500 m (N_{w500}).

2.3. Statistical analysis

Exposure-response relationships between wind turbine exposures and symptoms were analyzed using logistic regressions, where the outcome variables symptom frequencies were dichotomized into low frequency (score = 0) and increased frequency (score > 0). Analyses were performed mainly using two types of exposure assessments: 1) distance from each house to the closest wind turbine (D_w) and 2) the number of wind turbines within 1000 m around participants' home (N_{w1000}). In the first exposure criteria, distance was included as the logarithm base 10 of the distance ($log_{10}D_w$), taking into account that A-weighted, C-weighted, and G-weighted sound levels attenuates logarithmically with distance (Tachibana et al., 2014). Lowering the distance threshold for exposures from 1000 m to 500 m or defining exposures as "distance to wind turbines" (i.e. not log-transformed) can be interesting since environmental regulations usually establish setback distances for wind turbines lower than 1000 m (e.g. 500 m). Therefore other types of exposure asessments i.e. distance to the closest wind turbine (D_w) and number of wind turbines within 500 m (N_{w500}), were also explored and included as Supplementary information.

All adjusted models (Model 1, 2, 3 and 4) included measured sociodemographic characteristics (Table 1). Model 2, 3 and 4 included additional confounders such as personal reactions (annoyance, health risk perception and behavioural interference) to other environmental exposures (noise from sources different from wind turbines and odor). In Model 2 only those additional variables that were identified as confounders were added to the model. In order to decide which of the potential confounders must be controlled for in the analyses, we used the "significant-test-of-the-covariate" strategy, in which a variable is controlled if the coefficients indicating association with exposure and the outcome of interest, are significantly different from zero at some predetermined significance level. Often a 0.05 significance level is chosen, but previous studies have shown that much higher levels (0.20 or more) should be used for confounder selection, since significance-test strategies perform best (i.e. produced less bias in the estimators) when the alpha level was set to higher than conventional levels (i.e., 0.20 rather than 0.05) (Dales and Ury, 1978; Mickey and Greenland, 1989; Maldonado and Greenland, 1993). Therefore, in Model 2, variables for control were selected only if they were not intermediate variables, and its association with exposure and the outcome of interest was statistically significant at $p<0.20$. We should note that this high level of significance ($p<0.20$) was only used for the selection of confounders, and all the remaining analyses of this study were based on a conventional level of significance ($p<0.05$). In Model 3, all variables on personal reactions (annoyance, health risk perception and behavioural interference) to other environmental exposures were included to the model. Model 4 further included two potential mediators: negative appraisal of the presence of wind turbines (i.e. individuals that spontaneously mentioned "presence of wind turbines" as one of the main disadvantages of living in the countryside), and annoyance due to wind turbine noise (i.e. individuals who spontaneously responded in the section "others", that the origin of the annoying noise was the wind turbines). The mediating role of these variables was assessed using mediation analysis.

3. Results

3.1. Demographics and wind turbine exposures

The minimum distance between a residence and the closest wind turbine was 167 m and the maximum distance was 8983 m, while the mean and median of the distances to the closest wind turbine were 2052 m and 1712 m, respectively. The maximum number of wind turbines within 1000 m of each residence was 8 (mean of 0.38 wind turbines). The number and characteristics (capacity, rotor diameter and hub height) of the wind turbines located in each of the six study areas in Denmark (extended 1 km in all four directions) are shown in Table 2, as well as the characteristics of the wind turbines that are closest to each of the 454 households. The characteristics of the wind turbines located at <500 m, 500-1000 m, 1000-2000 m and >2000 m to the closest study residence, were not significantly different from each other in terms of capacity, rotor diameter and hub height (Table 2). The summary of wind turbine exposures at the residences located in the study areas are shown in more detail in Supplemental information. The socio-demographic characteristics of the respondents (N = 454, response rate = 40.5%) are presented in Table 1. The response rate at each of the study areas is shown in Table 3. The response rate was not significantly different among region I, II, IV, V and VI, but was higher at study area III (Table 3). However, exposure in study area III is not on the extremes of the exposure distribution, and the higher response rate from study area III does seem to indicate the existence of non-response bias (i.e. participation in the study related to the exposure status). This is also demonstrated when a non-response bias analysis is performed comparing the exposure level of respondents and non-respondents. Non-response analysis of wind turbines exposures (D_w, $log_{10}D_w$, N_{w1000} and N_{w500}), and basic demographical features (i.e. gender and age), showed no significant differences between respondents and non-respondents (Table 3).

3.2. Personal reactions to the presence of wind turbines, noise and odor, and symptoms

Only five individuals (1%) responded at their own initiative (open-ended question) that one of the main disadvantages of living in the countryside was the presence of wind turbines (i.e. negative appraisal of the presence of wind turbines).

About 27% of the residents (N=121) were annoyed by noise outside their residences (80 residents were "slightly annoyed", 16 were "moderately annoyed", 9 were "very annoyed" and 3 were "extremely annoyed"). Four individuals stated that they were concerned about the health risks of noise exposure at their residences, and 12 stated that outdoor noise prevented them from properly ventilating their homes or from performing outdoor activities that they wished to (i.e. behavioural interference). Regarding the noise sources, 9 individuals (7% of those annoyed by noise) named wind turbines as the source of noise, while 112 individuals named sources different from wind turbines. Fifty-six individuals (46%) identified the noise as originated by local road traffic, 36 individuals (30%) as being originated from agricultural activities in the area, 12 individuals (10%) named other sources (e.g. factories, shooting fields, dogs) and for 8 individuals (7%), the noise source was unknown.

Regarding odor annoyance, about 45% of the residents (N=205) were annoyed by odor pollution at their residences, 151 individuals being "slightly annoyed", 31 "moderately annoyed", 15 "very annoyed" and 8 "extremely annoyed". A total of 19 individuals (4%) were concerned about the potential negative effects that odor exposure may have on their health and 51 (11%) stated that their behavior was affected by the existence of odor in their residential area. All residents characterized the perceived odor as farming/animal waste odor. Seven out of the nine individuals that named wind turbines as the source of noise, reported to be also annoyed by agricultural odors.

The number and percentage of people being “Not annoyed”, “Slightly annoyed”, “Moderately annoyed”, “Very annoyed”, “Extremely annoyed” due to noise and due to odor, disaggregated by distance to the closest wind turbine and number of wind turbines within 1000 m is shown in Table 4.

Regarding idiopathic symptoms, the number and percentage of individuals that experienced increased frequency of symptoms (i.e. degree=1, 2, 3 or 4) in relation to “never or very rarely” (i.e. degree=0) were the 44 individuals (10%) for dizziness, 38 (8%) for difficulty concentrating, 67 (15%) for headache, 55 (12%) for unnatural fatigue, and 19 (4%) for nausea.

3.3. Identification of confounders and mediators

Table 5 shows the association between: 1) exposures and potential confounders and mediators, and 2) potential confounders and mediators, and symptoms. Regarding the potential confounders, we investigated whether each potential confounding variable was associated with the exposure of interest and whether it was associated with the outcome of interest, at a level of significance $p<0.20$ (i.e. higher than the conventional level of significance $p<0.05$, following the criteria of Maldonado and Geenland, 1993). We note that this high level of significance ($p<0.20$) was only used to identified confounders, and the conventional level $p<0.05$ was used for all other statistical analyses. Variables associated with $\log_{10}D_w$ at $p<0.20$ were: 1) behavioural interference due to noise from sources different from wind turbines, 2) odor annoyance, 3) concern about potential health effects of odors, and 4) behavioural interference due to odor exposures at the residence (Table 5). These variables were in turn associated with unnatural fatigue, headache, difficulty concentrating and dizziness, but not with nausea (Table 5). Therefore, confounding variables in the association of wind turbines exposures ($\log_{10}D_w$) and four of the symptoms (unnatural fatigue, headache, difficulty concentrating and dizziness) were: 1) behavioural interference due to noise from sources different from wind turbines, 2) odor annoyance, 3) concern about potential health effects of odors, and 4) behavioural interference due to odor exposures at the residence. In the case of the association of wind turbines exposures ($\log_{10}D_w$) and nausea, identified confounding variables were: 1) odor annoyance, 2) concern about potential health effects of odors, and 3) behavioural interference due to odor exposures at the residence.

Regarding potential mediators, wind turbine noise annoyance was associated with wind turbines exposure (Table 5). Logistic regressions adjusted for sociodemographic characteristics showed that the odds for a citizen of being annoyed by wind turbine noise significantly decreased with the $\log_{10}D_w$ (OR_{adj} = 0.02; 95% CI = 0.00–0.29, for each unit increase in $\log_{10}D_w$). Furthermore, the odds of being annoyed by wind turbine noise significantly increased with the number of wind turbines within 1000 m distance from the dwelling (OR_{adj} = 1.83; 95% CI = 1.16–2.90) (adjusted for socio-demographic characteristics). However, wind turbine noise annoyance was not further associated with symptoms. Negative appraisal of wind turbines was neither associated with wind turbines exposure not with symptoms (Table 5). Therefore these two potentially mediating variables (i.e. turbine noise annoyance and negative appraisal of wind turbines) do not fulfill the necessary requirements to be mediators in the association of wind turbines exposure and symptoms.

3.4. Association between proximity to wind turbines and symptoms

The unadjusted exposure-response models are shown in Figure 1. Residential distance to the closest wind turbine (expressed as $\log_{10}D_w$) was negatively associated with increased occurrence of three idiopathic symptoms (i.e. unnatural fatigue, difficulty concentrating and dizziness). After adjusting for socio-demographic characteristics associations for “unnatural fatigue” and “difficulty concentrating” remained significant (OR_{adj}=0.38, 95%CI = 0.15-1.00 and OR_{adj}=0.26, 95%CI = 0.08-0.83 respectively, for each unit increase in $\log_{10}D_w$) (Table 6). When the models were additionally adjusted for identified confounders, residential distance to the closest wind turbine was not associated with any of the idiopathic symptoms ($p>0.05$). Similar results were obtained in fully adjusted models (i.e. when all potential confounders were included in the model, and when the model included all potential confounders and mediators considered in the study). However, the confounder-adjusted models only had moderate reductions in the estimated effect sizes of exposure (e.g. $OR_{adj}=0.46$ Vs. $OR_{adj}=0.38$ for unnatural fatigue).

When exposure to wind turbines was assessed as the number of wind turbines within 1000 m distance (N_{w1000}), unadjusted models and those adjusted for socio-demographic characteristics showed a significant association with "unnatural fatigue" and "headache" ($OR_{adj}=1.35$, 95%CI = 1.07-1.70 and $OR_{adj}=1.26$, 95%CI = 1.00-1.58, respectively) (Table 6). In models adjusted for additional confounders and fully adjusted models, there was not a significant relationship between number of wind turbines and idiopathic symptoms ($p>0.05$). Again, however, the reductions in the effect size estimates after control for confounding were only moderate.

Multiple comparisons as those carried out in this study, tend to increase the risk of Type 1 error. To account for the number of comparisons being performed, the Bonferroni correction for the level of significance (dividing the selected level of significance by the number of statistical tests) can be used. In our study, using the Bonferroni correction resulted in no significant association between proximity to wind turbines and symptoms.

The analyses performed using distance to the closest wind turbine (D_w) as exposure metric (instead of $\log_{10}D_w$), showed in all cases (not adjusted and adjusted models) non-significant associations, with OR=1.00 (Supplementary information). However, the spuriously high precision (overly narrow confidence intervals) strongly suggests the existence of biased results. The results of using the "number of wind turbines within 500 m" (N_{w500}) as exposure variable are shown in Supplementary Information. Although lowering the exposure threshold from 1000 m to 500 m can be interesting since environmental regulations, in our study 438 residents (out of 454) did not have any wind turbine within 500 m to their residence, while 13 residents were living within 500 m of one wind turbine, and 3 residents were living within 500 m of two wind turbines. Therefore using this approach introduces some methodological problems such as complete separation in the logistic regression analysis, and increases the risk of having differential misclassification.

Finally, as expected, unadjusted and adjusted models did not show any significant relationship between residential proximity to wind turbines and the dummy symptoms (i.e. respiratory and sensory irritation symptoms) (data not shown).

4. Discussion

We investigated the association between residential proximity to wind turbines and idiopathic symptoms in a population-level setting where the participants were blind to the aim of the study. When only socio-demographic characteristics of the residents were considered as confounders, our study yielded significant associations between proximity to wind turbines and three idiopathic symptoms (i.e. difficulty concentrating, unnatural fatigue and headache). Further examination revealed that these associations were confounded by personal reactions to other environmental exposures occurring in the countryside (i.e. odor and noise from sources different from wind turbines). When these confounders were included in the analysis, we did not observe a significant association between wind turbines and symptoms, and the parameter estimates were attenuated toward zero.

When assessing the adverse effects of wind turbines it is important to consider two types of effects: indirect and direct effects. The majority of studies acknowledge the existence of indirect effects, i.e. that wind turbines might cause annoyance, stress, or sleep disturbance, which in turn can have some consequences for human health. According to Schmidt and Klokker, (2014), it is possible that symptoms such as headache, dizziness, nausea, sleep disorders and lack of concentration, could occur as a result of sleep disturbance. However, the existence of indirect (stress-mediated) mechanisms, although frequently mentioned in the literature, has not been demonstrated in studies using methods capable of elucidating such pathways (McCunney et al., 2014). In our study we did find a significant association between residential proximity to wind turbines and wind turbine noise annoyance, but annoyance was not further associated with symptoms. In the case of negative appraisal of the presence of wind turbines, this was related neither to residential proximity nor to symptoms. Therefore, our results did not support the existence of these mediating pathways and an indirect effect could not be established.

Even though several studies have suggested the existence of stress-mediated effects, the significance of this indirect mechanism is often discounted because “direct causal links” could not been established. In fact, the existence of direct health effects is highly controversial, and has been object of heated scientific discussions in the literature (Nissenbaum et al., 2012; Hanning and Evans, 2012a; 2012b; Chapman, 2012; Ollson et al., 2013). Some studies defend the plausibility of a series of physiological mechanisms in which wind turbines could directly affect health. However, recent reviews of the research literature on wind turbines and health (Knopper and Ollson, 2011; Schmidt and Klokker, 2014; McCunney et al., 2014) have reached the conclusion that to date epidemiological evidence for wind turbines being directly harmful to health is only supported by case-series reports unpublished in the peer reviewed literature, which may be seriously affected by various sources of bias.

In our study we investigated the existence of this direct relationship. Previous studies using distance as proxy found higher percentage of respondents living close to wind turbines reporting altered health (e.g. headaches, migraines, hearing problems and tinnitus) than those living further away from wind turbines, but differences were not significant except for unnatural fatigue (Krogh et al., 2011). However this study can be affected by sampling bias. Studies using calculated A-weighted equivalent sound pressure level (Pedersen and Persson-Waye, 2004; 2007; Pedersen et al., 2009; Pedersen et al., 2011) did not find an association between wind turbine noise exposure and headache and fatigue.

In our study, distance to the closest wind turbine (not log-transformed, D_w) was not significantly associated with idiopathic symptoms (Supplementary information), but incorrectly predicted very narrow confidence intervals. This can be the result of a misspecifed model, due to using untransformed distances in the logistic regression analysis which can violate the linerarity assumption. We observed significant relationships between $\log_{10}D_w$ and unnatural fatigue and difficulty concentrating and between N_{w1000} and unnatural fatigue and headache, but only when models were not adjusted or only adjusted for sociodemographic characteristics (Model 1 in Table 6). The results based on log-distances are in agreement with Nissenbaum et al. (2012), who observed dose-response relationships between log-distance to the closest wind turbine and some health outcomes including vertigo, after controlling for gender, age, and household clustering, with the effect diminishing with increasing log-distance. The authors also pointed out that they expected log-distance to fit health outcomes better than distance, given that noise drops off as the log of distance. Despite these indications of direct effects in our study, further analyses suggested a more complicated picture and cast doubt on these findings. The respondents of our study identified two main environmental exposures from local sources in the countryside: malodor from farming and agricultural activities and noise from sources different from wind turbines, mainly from traffic and agricultural activities. We investigated whether the relation between proximity to wind turbines and non-specific symptoms could be confounded by personal reactions to these environmental exposures typically occurring in the same contexts as wind turbines. Our study showed that annoyance, health risk perception and behavioural interference caused by agricultural odor exposures, and behavioural interference caused by noise different from wind turbines were confounders of the association between proximity to wind turbines and idiopathic symptoms (Table 5). The relation between these environmental confounders and symptoms is explained by the fact that self reported health effects of people living in proximity to wind turbines are not unique to wind turbines. In our study agricultural/farming activities were identified as the main source of environmental exposures among residents living in rural areas. Personal negative reactions to these exposures, widespread in many rural areas, are known to be associated with health effects (Blanes-Vidal, 2015). On the other hand, the relation between wind turbines proximity and the identified confounders (e.g. odor annoyance) may be partly caused by a concurrent exposure. When the dose-response models were adjusted for identified and potential confounders (Model 2 and Model 3 respectively, in Table 6), our study did not show evidence of a relationship between residential proximity to wind turbines and health symptoms.

Our study has some limitations. The cross-sectional study design has a limited capability to determine causality. We used a surrogate of exposure to wind turbines (i.e. residential proximity), and like any surrogate, it may not represent actual exposures. First, the noise created by the wind turbine will depend on its size and characteristics (as well as in other factors such as wind speed, turbulence and topography). Second, the distance to the residences may be related to the size of the wind turbines, e.g. larger wind turbines being located at further distances from the dwellings. In our study the characteristics of the wind turbines located at <500 m, 500-1000 m, 1000-2000 m and >2000 m to the closest residence, were not significantly different from each other in terms of capacity, rotor diameter and hub height. Most previous studies have used modeled noise level as exposure assessment method (Pedersen, 2011; Bakker et al., 2012), while some studies have used control groups far away from the exposure sites (Shepherd et al. 2011, Kuwano et al. 2014). Distance is an easily obtainable proxy of exposure to wind turbines. The main advantage of using distance as exposure assessment method is that, due to its simplicity, it may allow to estimate exposures in larger populations. However, the tradeoff between simplicity and accuracy needs to be carefully considered. Another limitation of our study is the lack of information on sleep disturbance, since it would have been interesting to investigate its potential association with exposure. Non-response bias may exist, whereby individuals living close to wind turbines may have been more likely to respond to the survey than individuals living further away. However, non-response analysis of D_w, $\log_{10}D_w$, N_{w500}, N_{w1000} and basic demographical features (i.e. gender and age), showed no significant differences between respondents and non-respondents.

We assessed residential exposure to wind turbines based of distances to nearby wind turbines, and obtained information on symptoms, demographics and personal reactions to wind turbines and other environmental co-exposures. We identified confounders using confounders' selection criteria and used adjusted logistic regression models to estimate associations. After controlling for personal reactions to other environmental co-exposures, we did not observe a significant relationship between residential proximity to wind turbines and symptoms, and the parameter estimates were attenuated toward zero. Confounding is a major problem in epidemiological research, particularly when small effects are investigated. Our study suggests that isolated associations between wind turbines exposures and health outcomes reported in the literature may be partly due to confounding bias. Although there is no established method for identifying a pre-specified set of important confounders and it is virtually impossible in practice to take account of every possible confounding factor, future studies on health effects of wind turbines should consider including additional important confounders in the models. The list of these potential confounders should not be generated solely on the basis of demographic variables or wind turbine noise-related factors, but also considering relevant environmental co-exposures.

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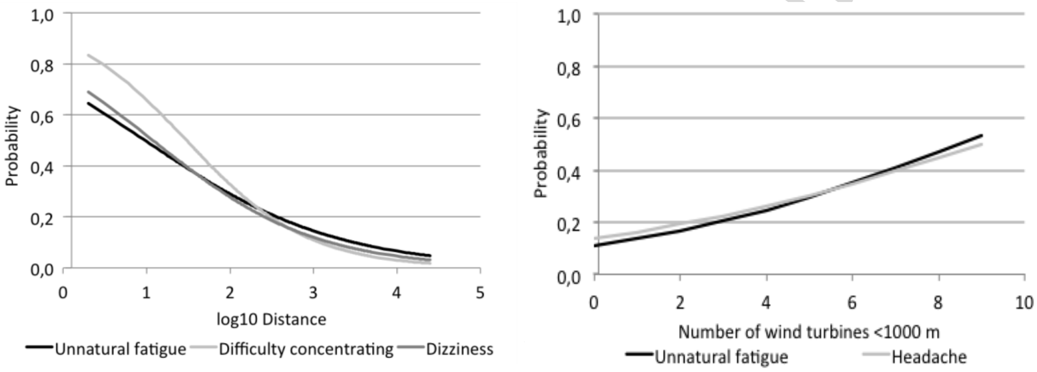

a b

Figure 1. Exposure-response associations from univariate models (not adjusted). a. Exposure expressed as $\log_{10}$ of distance to the closest wind turbine (Unnatural fatigue: OR=0.42, 95%CI=0.17-1.02, p=0.05; Difficulty concentrating: OR=0.25, 95%CI=0.08-0.75, p=0.01; Dizziness: OR=0.35, 95%CI=0.13-0.96, p=0.04). b. Exposure expressed as number of wind turbine within 1000 m to the residence (Unnatural fatigue: OR=1.28, 95%CI=1.03-1.59, p=0.03; Headache: OR=1.23, 95%CI=0.99-1.52, p=0.06)

Table 1. Summary of socio-demographic characteristics of the respondents, N=454

	N (%)
Gender	
Male	245 (54)
Female	209 (46)
Age[a]	
<40 years	80 (18)
40-60 years	210 (46)
>60 years	164 (36)
Smoking	
No	389 (86)
Yes	65 (14)
Years living in the household[a]	
≤25 years	218 (48)
>25 years	236 (52)
Children at home	
No	343 (76)
Yes	111 (24)
Time spent at home[a]	
≤100 h/week	184 (41)
>100 h/week	270 (59)
Employment status	
Self employed	61 (13)
Salaried employee	215 (47)
Not employed[b]	178 (39)
Health conditions	
Acute respiratory	46 (10)
Chronic respiratory	41 (9)
Other health conditions[c]	67 (15)

[a] Mean ± STD: Age: 54±14 years, Years living in the area, 30±20, Time spent at home, 114±37 h/week

[b] Not employed residents include e.g. pensioners, students, housewife/husbands.

[c] The most common self-reported health conditions were diabetes, cardiovascular conditions and digestive diseases.

Table 2. Number and wind turbines characteristics (capacity, rotor diameter and hub height)

	Number and characteristics of all the wind turbines that are located in each of the six study areas in Denmark[1]							Number and characteristics of the wind turbines that are closest to each of the454 households[2]				
	Total	Study Areas[1]						Total	Distance to the closest household			
		I	II	III	IV	V	VI		<500 m	500-1000 m	1000-2000 m	>2000 m
Number	219	0	14	18	21	23	101	454	16	65	198	175
Capacity (kW)	786 (11-3600)	0	919 (600-1500)	596 (150-1000)	984 (11-3600)	771 (500-1000)	679 (18-2000)	714 (623)	821 (402)	729 (491)	696 (666)	719 (637)
Rotor diameter (m)	47 (10-120)	0	52 (42-64)	42 (24-54)	49 (13-107)	49 (39-54)	44 (10-80)	42 (19)	48 (13)	42 (17)	41 (20)	43 (19)
Hub height (m)	45 (16-90)	0	47 (40-50)	40 (18-46)	50 (18-90)	47 (23-50)	44 (16-60)	41 (14)	44 (6)	40 (11)	40 (15)	42 (15)

[1] Average (Min-max). The study areas are I: Anholt; II: Keldsnor; III: Sundeved; IV: Ulfborg; V: Tange and VI: Lindet.
[2] Average (Standard deviation). One factor ANOVA showed not significant differences among wind turbines depending on the distance to the closest household (<500 m, 500-1000 m, 1000-2000 m and >2000 m) regarding capacity (p=0.87), rotor diameter (p=0.48) and hub height (p=0.30).

Table 3. Non-response bias analysis of residential exposures, gender, age and regions [1]

		Respondents		Non respondents		p-value
		Mean	STD	Mean	STD	
Log_{10} Distance to the closest wind turbine ($log_{10}D_w$)		3.11	0.24	3.07	0.24	0.05[2]
Distance to the closest wind turbine (D_w)		1489	740	1374	719	0.05[2]
Number of wind turbines <1000 m (N_{w1000})		0.58	1.22	0.77	1.35	0.07[2]
Number of wind turbines <500 m (N_{w500})		0.07	0.29	0.08	0.32	0.60[2]
		Number	%	Number	%	
Gender	Males	163	58	190	56	0.60[3]
	Females	117	42	148	44	
Age	<40 years	40[a]	14	66	20	0.23[3]
	40-60 years	128[a]	46	141	42	
	>60 years	112[a]	40	131	39	
Region	I (Anholt)	14[a]	3	32	5	0.02[3]
	II (Keldsnor)	83[a]	18	132	20	
	III (Sundeved)	109[b]	24	106	16	
	IV (Ulfborg)	88[a]	20	127	18	
	V (Tange)	78[a]	18	137	20	
	VI (Lindet)	82[a]	17	133	21	

[1] Analysis on gender and age are on respondents and non-respondents of three regions ($N_{respondents}$ = 280, $N_{non-respondents}$=338). Data from non-respondents were provided by local authorities (Region Syddanmark) and they cover three study regions (II: Keldsnor; III: Sundeved and VI: Lindet).

[2] Two sample t-test
[3] Chi-squared test of proportions. When more than two groups are compared, same letters indicate no significant differences between groups.

Table 4. Noise and odor annoyance levels reported by residents disaggregated by distance from their residence to the closest wind turbine (D_w) and number of wind turbines within 1000 m (N_w)

	Noise annoyance				
	Not annoyed	Slightly annoyed	Moderately annoyed	Very annoyed	Extremely annoyed
D_w					
<1000 m	60 (74)	11 (14)	6 (7.4)	2 (2.5)	2 (2.5)
1000-2000 m	155 (79)	33 (17)	5 (2.5)	3 (1.5)	1 (0.5)
2000-3000 m	50 (68)	20 (27)	2 (2.7)	1 (1.4)	0 (0)
>3000 m	81 (79)	16 (16)	3 (2.9)	3 (2.9)	0 (0)
N_w					
0	286 (77)	69 (18)	10 (2.7)	7 (1.9)	1 (0.3)
1	30 (83)	2 (5.6)	3 (8.3)	2 (5.6)	0 (0)
2 or more	30 (67)	9 (20)	3 (6.7)	1 (2.2)	2 (4.4)
	Odor annoyance				
	Not annoyed	Slightly annoyed	Moderately annoyed	Very annoyed	Extremely annoyed
D_w					
<1000 m	46 (57)	22 (27)	8 (10)	3 (3.7)	2 (2.5)
1000-2000 m	99 (50)	74 (38)	12 (6.1)	8 (4.1)	4 (2.0)
2000-3000 m	38 (52)	27 (37)	4 (5.5)	3 (4.1)	1 (1.4)
>3000 m	66 (64)	28 (27)	7 (6.8)	1 (1.0)	1 (1.0)
N_w					
0	189 (51)	134 (36)	28 (7.5)	14 (3.8)	8 (2.1)
1	20 (56)	12 (33)	3 (8.3)	1 (2.8)	0 (0)
2 or more	40 (89)	5 (11)	0 (0)	0 (0)	0 (0)

Table 5. Association between personal reactions to wind turbines and other environmental exposures (potential confounders and mediators), and 1) exposures and 2) health symptoms

	Prevalence of confounders and mediators		Association with exposures		Association with symptoms				
	N	%	Log_{10}Distance to closest wind turbine ($log_{10}D_w$)	Number of wind turbines <1000 m (N_w)	Nausea	Unnatural fatigue	Headache	Difficulty concentrating	Dizziness
Potential confounders[1]									
Annoyance (noise from other sources)	97	21	1.13 (0.62-2.02) p=0.69	1.11 (0.90-1.36) p=0.34	1.74 (0.65-4.72) p=0.27	**2.17 (1.18-3.99) p=0.01**	**2.82 (1.62-4.92) p=0.0003**	**2.66 (1.33-5.32) p=0.006**	0.80 (0.36-1.79) p=0.59
Health concern (noise from other sources)	4	0.9	0.48 (0.02-10.1) p=0.63	0.85 (0.23-3.07) p=0.80	[3]	[3]	[3]	[3]	[3]
Behavioural interference (noise from other sources)	12	2.6	**0.27 (0.04-1.77) p=0.17**	**1.41 (1.01-1.96) p=0.04**	[3]	**5.60 (1.71-18.3) p=0.004**	**4.38 (1.35-14.2) p=0.01**	**3.88 (1.00-14.5) p=0.05**	**3.26 (0.85-12.5) p=0.09**
Annoyance (odor)	205	45	**0.53 (0.31-0.90) p=0.02**	0.99 (0.82-1.19) p=0.90	1.37 (0.54-3.43) p=0.50	**1.54 (0.87-2.71) p=0.14**	**1.99 (1.18-3.38) p=0.01**	**2.87 (1.41-5.84) p=0.004**	**1.52 (0.81-2.84) p=0.19**
Health concern (odor)	19	4.2	**0.27 (0.06-1.21) p=0.09**	1.17 (0.82-1.67) p=0.38	**2.89 (0.62-13.5) p=0.18**	**3.64 (1.32-10.0) p=0.01**	**3.65 (1.38-9.63) p=0.01**	**4.35 (1.48-13.0) p=0.008**	**6.27 (2.33-17.0) p=0.0003**
Behavioural interference (odor)	53	12	**0.56 (0.24-1.33) 0.19**	**1.17 (0.92-1.48) p=0.19**	**2.88 (0.99-8.35) p=0.05**	**2.78 (1.38-5.61) p=0.004**	**1.84 (0.91-3.72) p=0.09**	**4.22 (1.98-8.99) p=0.0002**	**3.38 (1.61-7.06) p=0.001**
Potential mediators[2]									
Negative appraisal of	5	1.1	0.63	1.02	[3]	[3]	1.45	[3]	[3]

presence of wind turbines			(0.05-8.62) p=0.75	(0.44-2.38) p=0.96			(0.16-13.2) p=0.74		
Annoyance from wind turbine noise	9	2	**0.04** **(0.00-0.37)** **p=0.005**	**1.49** **(1.06-2.11)** **p=0.02**	2.97 (0.35-25) p=0.32	0.91 (0.11-7.38) p=0.93	1.67 (0.34-8.22) p=0.53	1.38 (0.17-11.3) p=0.76	1.17 (0.14-9,57) p=0.89

[1] p-values<0.20 are indicated in bold print.

[2] p-values<0.05 are indicated in bold print.

[3] Not enough cases of residents reporting health concern, behavioural interference (noise from other sources) or negative appraisal of presence of wind turbines, and specific symptoms

Table 6. Association between residential proximity to wind turbines and health symptoms adjusted for sociodemographic characteristics (Model 1), adjusted for sociodemographic characteristics and all identified confounders (Model 2), adjusted for sociodemographic characteristics and all other potential confounders (Model 3) and adjusted for sociodemographic characteristics and all other covariates (all potential mediators and confounders) (Model 4)[1]

	Model 1 : Adjusted for sociodemographic characteristics	Model 2: Adjusted for sociodemographic characteristics and all identified confounders[2]	Model 3: Adjusted for sociodemographic characteristics and all other potential confounders	Model 4: Adjusted for sociodemographic characteristics and all other covariates (all potential mediators and confounders)
Exposure measured as $\log_{10}$ of the residential distance to the closest wind turbine ($\log_{10}D_w$)				
Nausea	0.44 (0.09-2.07) p = 0.30	0.39 (0.08-1.99) p=0.26	0.39 (0.08-1.98) p = 0.26	0.40 (0.08-2.10) p = 0.28
Unnatural fatigue	**0.38 (0.15-1.00)** **p = 0.05**	0.46 (0.17-1.23) p=0.12	0.45 (0.17-1.22) p = 0.12	0.44 (0.16-1.21) p = 0.11
Headache	0.45 (0.20-1.05) p = 0.07	0.53 (0.22-1.27) p=0.16	0.51 (0.21-1.25) p = 0.14	0.51 (0.21-1.27) p = 0.15
Difficulty concentrating	**0.26 (0.08-0.83)** **p = 0.02**	0.30 (0.09-1.07) p=0.07	0.28 (0.08-1.01) p = 0.06	0.28 (0.08-1.04) p = 0.06
Dizziness	0.39 (0.14-1.08) p = 0.07	0.47 (0.17-1.34) p=0.16	0.47 (0.17-1.34) p = 0.16	0.46 (0.16-1.33) p = 0.15
Exposure measured as number of wind turbines within 1000 m from the residence (N_{w1000})				
Nausea	0.98 (0.59-1.63) p = 0.94	0.99 (0.61-1.62) p = 0.97	1.01 (0.59-1.72) p = 0.96	1.00 (0.58-1.72) p = 0.99
Unnatural fatigue	**1.35 (1.07-1.70)** **p = 0.01**	**1.30 (1.00-1.69)** **p = 0.05**	1.28 (0.99-1.67) p = 0.06	1.29 (0.99-1.68) p = 0.06
Headache	**1.26 (1.00-1.58)** **p = 0.05**	1.23 (0.96-1.57) p=0.10	1.22 (0.96-1.57) p = 0.11	1.22 (0.95-1.57) p = 0.12
Difficulty concentrating	1.14 (0.86-1.51) p = 0.36	1.05 (0.77-1.43) p=0.75	1.05 (0.77-1.43) p = 0.75	1.05 (0.76-1.43) p = 0.78

Dizziness	1.24 (0.95-1.61) p = 0.11	1.17 (0.88-1.55) p=0.28	1.23 (0.93-1.64) p = 0.14	1.24 (0.94-1.65) p = 0.13

[1] Significant associations at $p<0.05$ are highlighted in bold.
[2] Covariates that were identified as confounders as shown in Table 5

Highlights

- Concerns have been raised about the potential health effects of wind turbines.
- No study on wind turbines and health has controlled for other co-exposures.
- Other environmental co-exposures are confounders.
- After controlling for them, there was no wind turbines-symptoms association.
- Associations reported in the literature may be due to confounding bias.